# Economic Power Dispatch of Distributed Generators in a Grid-Connected Microgrid

Hernández, Adriana Carolina Luna; Aldana, Nelson Leonardo Diaz; Andrade, Fabio ; Graells, Moises; Guerrero, Josep M.; Vasquez, Juan Carlos

*Published in:*
Proceedings of the 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia)

*DOI (link to publication from Publisher):*
10.1109/ICPE.2015.7167927

*Publication date:*
2015

*Document Version*
Early version, also known as pre-print



*Citation for published version (APA):*
Hernández, A. C. L., Aldana, N. L. D., Andrade, F., Graells, M., Guerrero, J. M., & Vasquez, J. C. (2015). Economic Power Dispatch of Distributed Generators in a Grid-Connected Microgrid. In *Proceedings of the 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia)* (pp. 1161 - 1168 ). IEEE Press. https://doi.org/10.1109/ICPE.2015.7167927

# Economic Power Dispatch of Distributed Generators in a Grid-Connected Microgrid

Adriana C. Luna*, Nelson L. Diaz*†, Fabio Andrade‡, Moisès Graells§,
Josep M. Guerrero*, and Juan C. Vasquez*
*Dept. Energy Technology, Aalborg University, Aalborg, Denmark, http://www.microgrids.et.aau.dk
†Dept. Electronic Engineering, Universidad Distrital Francisco Jose de Caldas, Bogota, Colombia
‡Dept. Electrical and Computer Engineering, Universidad de Puerto Rico, Mayaguez, Puerto Rico
§Dept. Chemical Engineering, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
acl@et.aau.dk, nda@et.aau.dk, far@et.aau.dk, moises.graells@upc.edu, joz@et.aau.dk, juq@et.aau.dk

***Abstract*—Grid-connected microgrids with storage systems are reliable configurations for critical loads which can not tolerate interruptions of energy supply. In such cases, some of the energy resources should be scheduled in order to coordinate optimally the power generation according to a defined objective function. This paper defines a generation-side power scheduling and economic dispatch of a grid-connected microgrid that supplies a fixed load and then, the scheduling is enhanced by including penalties in order to increase the use of the renewable energy sources and guarantee a high state of charge in the storage system for the next day. Linear models are proposed for the scheduling which are implemented in GAMS. The microgrid model is obtained deploying MATLAB/Simulink toolbox and then downloaded into dSPACE 1006 platform based on real-time simulation to test the economic dispatch. A compromise between cost and use of renewable energy is achieved.**

***Keywords*—Economic dispatch, generation-side scheduling, microgrids, energy management system.***

## I. Introduction

A microgrid (MG) is composed of distributed generators (DG), energy storage systems (ESS) and loads, that can operate interconnected to the main grid or in islanded mode [1]. Particularly, grid-connected microgrids are commonly used as reliable configurations for critical loads which must be uninterruptedly fed [2]. However, when there are several resources available to supply the demand, they should be scheduled to get an optimal dispatch regarding specific objectives such as economical, technical and environmental aspects [2], [3].

Regarding economical issues and from the point of view of the owner of the microgrid, the main objective is to minimize the operating cost [3], and additional topics on the optimization process have been included refer to the full use of renewable energy sources (RES) due to their intermittent nature, as well as the prolongation of the life time of the ESS [4], [5]. As illustration, [6] and [7] present energy management systems performed to maximize power generation of a hybrid active power generator for a grid-connected microgrid based on wind turbine (WT) generator (WT+ESS) and a photovoltaic (PV) generator (PV+ESS) respectively.

In addition, when an ESS is included in the MG, its behavior should be taken into account in the scheduling [8]. For instance, the minimization of the energy cost and maximization of batteries lifetime in a microgrid is proposed in [9] and a battery management system of a microgrid for both grid-connected and autonomous modes is presented in [10]. Likewise, an energy management strategy is proposed in [11] for operating PV power plants with ESS in order to endow them with a constant production that can be controlled. In that work, the ESS behaves like a system load, recharging the ESS from the grid to achieve a desired state of charge (SoC) value before starting operation the next day i.e. minimizing the SOC deviation with regard to a SOC reference value. Similar approach has been proposed in [12] where a constant power generation for PV systems is implemented and a certain percentage of the energy is cut off in a long-term operation when the output power reaches a certain level so, it is expected that the power reference for RES is defined by an optimal value in accordance with the power capability of each RES.

Moreover, hierarchical control is structured to deal with the behavior of the microgrids at different bandwidth. Upper level controls deal with optimal operation and power flow management whereas lower levels are responsible of power quality control and regulation of local variables [13]. At the primary level of control, the RES are regulated in order to follow a local maximum power point tracking (MPPT) algorithm or the power reference given by an energy management system which schedules the operation of DG in accordance to an optimization algorithm, then, DG work under constant current control inner loops. Meanwhile, ESS is charged or discharged based on the power unbalance between the generated and consumed power. Normally, when the ESS is completely charged and the load requests less power than available, the control mode of the DG changes in order to share equally between DG the power that the load requests [14]. Apart from that, banks of lead-acid batteries are commonly used in microgrids [2], [15]. In this sense, at least a two-stage charge procedure should be considered in order to ensure adequate life-time for batteries [15].

In this paper, some strategies of economic dispatch are considered minimizing the operating cost, which aim to reduce the energy consumption of the grid power, the SoC of the ESS and maximizing the use of the RES to supply permanently a constant load. The MG consists in two RES (a wind turbine (WT) and a photovoltaic (PV) panel), a battery, and a critical load connected to the grid by means of a AC/AC converter (Fig. 1).

Connecting the grid through a converter can be used to mitigate harmonics and other disturbances as referenced in [16]. The main grid will be assumed as a dispatchable unit and the ESS will support the fluctuations of generation. To be more precise, different stages for charging a bank of batteries are presented, as well as, how those stages interact with the operation of the microgrid. The paper is organized as follows: Section II describes the operation of the microgrid considered as study case, Section III presents the proposed optimization model, Section IV includes the simulation results and the Section V concludes the paper.

## II. Operation of the Microgrid

In a microgrid, RES are more likely to operate as constant power sources by flowing the power reference given by a MPPT algorithm or the power reference derived from an optimization procedure (PControl in Fig. 1). As consequence, DG composed by RES are controlled at the primary level by current control mode (CCM) inner loops [17]. The power reference provided by the scheduling process should be, at any case, small or equal to the power reference given by the MPPPT algorithm, consequently, RES will operate under *Pcontrol* (Fig. 1). Nevertheless, due to unpredicted variations on weather conditions the power reference will be given by the MPPT algorithm when the scheduled power is bigger than the MPPT value.

On the contrary, ESS is charged or discharged based on the power unbalance between the generated and consumed power. For that reason, the ESS is responsible of voltage bus regulation and it operates under voltage control mode (VCM) inner loops (typically $SoC \leq 95\%$) [17]. However, the most effective way of charging a lead-acid battery is by means of a two-stage procedure which involves two different control loops [15], [18], [19]. More precisely, VCM operation should be alternated by a constant voltage charge stage. Once the voltage per cell reaches a threshold value ($V_r$), known as the regulation voltage (typically $2.45 \pm 0.05$ V/cell), the battery voltage should be kept constant and the current at the battery will approach to zero asymptotically, and once it falls below a certain value, the battery may be considered as fully charged [15], [19]. At this point, the ESS takes as much power as needed to keep its battery voltage at $V_r$ [18]. Because of this, the ESS operates under CCM, and other distributed generator inside the microgrid should assume the regulation of the common bus.

On top of that, in this microgrid the power requested by the grid is conceived as a dispatchable power source providing the value defined by the scheduling process. In this case, the power grid is interconnected to the microgrid by means a power converter and operates under CCM by following the scheduled reference. However, when the battery array reaches the threshold voltage ($V_r$) the AC grid assumes the responsibility of voltage bus regulation, operating under VCM. In ligh of this, any power unbalance between the generated and consumed power will be assumed by the AC grid, ensuring reliable operation at the common bus of the microgrid.

## III. Proposed Optimization Model

This problem has been developed as a linear programming (LP) problem where the data are considered as the mean value for each elementary interval of scheduling.

### A. Parameters and variables

The parameters used in this model are presented in table I while the variables are included in table II.

TABLE I. Parameters of the model

| Name | Description | Value |
|---|---|---|
| $T$ | Time of scheduling | 24 [h] |
| $\Delta t$ | Duration of interval | 1 [h] |
| $n_g$ | Number of power sources | 3 |
| $n_k$ | Number of storage systems | 1 |
| $C(i,t)$ | Generation elementary cost | 0-8 [DKK/kWh] |
| $P_{g_{max}}(i,t)$ | Power max for generators | 0-5 [kW] |
| $P_L$ | Critical Load | 1.4 [kW] |
| $P_{losses}$ | Power losses | 100 [W] |
| $SoC_{max}(k)$ | State of Charge max | 100 [%] |
| $SoC_{min}(k)$ | State of Charge min | 50 [%] |
| $SoC(k_0)$ | Initial Condition | 75 [%] |
| $\varphi_{bat}(k)$ | SOC coefficient | 7.5503 [%/kWh] |
| $\xi(i)$ | penalty costs for RES | 0-8 [DKK/kWh] |
| $\chi(k)$ | reward costs for ESS | 0-8 [DKK/kWh] |

TABLE II. Variables of the model

| Related to | Name | Description |
|---|---|---|
| Decision var. | $P_g(i,t)$ | Power of the generators |
| | $COST$ | Cost |
| Auxiliary var. | $P_{bat}(k,t)$ | Power of the battery |
| | $SoC(t)$ | State of charge |

The scheduling is performed for $T$ hours in intervals of $\Delta t$ hours whereas the index $t$ is the elementary unit of time, $t = 1, 2, 3 \ldots . T$. The indexes ($i = 1, 2 \ldots . n_g$) and ($k = 1, 2 \ldots . n_k$) correspond to the subscripts related to the power sources and the energy storage systems respectively. The number of energy resources of the microgrid is set by means of $n_g$ and $n_k$. In this study case, there is a storage system ($n_k = 1$) and three power sources ($n_g = 3$): a photovoltaic panel, a wind turbine and the main grid.

The parameters $C(i,t)$ and $P_{g_{max}}(i,t)$ are set of real data that correspond to the cost of generation and the maximum power that the $i-th$ power source can provide. $P_L(t)$ is the load profile of the critical load which in this particular case is set to be 1.5kW for all time intervals. $P_{losses}$ represent the power losses in the inverters and are defined experimentally by power load tests as 100 W.

Regarding the energy storage systems, the parameters for each $k$ are $SoC_{max}(k)$, $SoC_{min}(k)$, $SoC_0(k)$ and $\varphi_{bat}(k)$. Specifically, the state of charge (SoC) in a

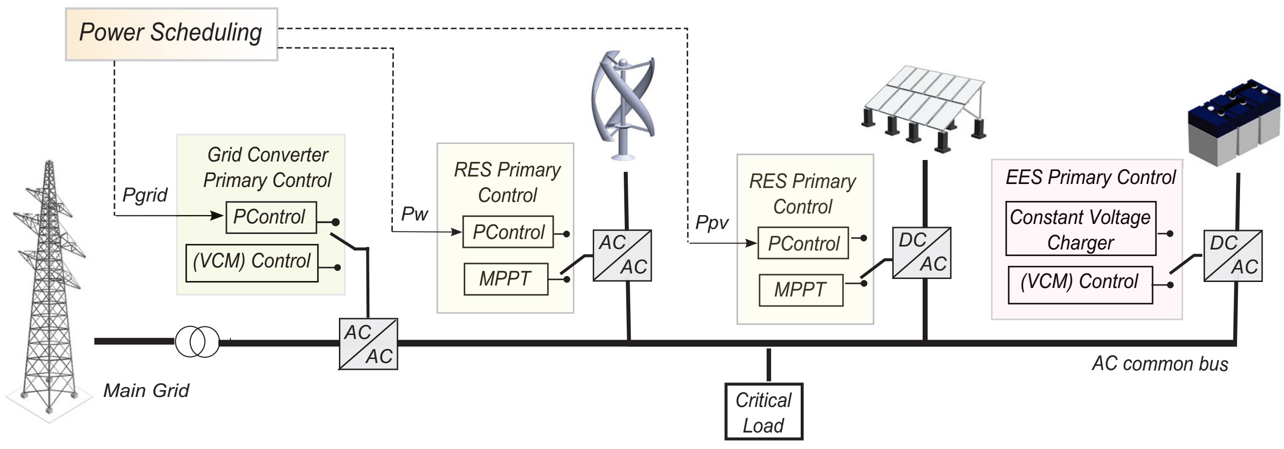


Fig. 1. Scheme of the microgrid used as study case

storage system represents the relation between the current capacity (in [Ah]) and the nominal capacity and is presented in percentage as a function of the current [18]. Assuming that the voltage of the storage system is constant ($Vbat_{nom}(k)$) in $\Delta t$, the current can be represented in terms of power $\left[I_{bat}(k,t) = \frac{P_{bat}(k,t)}{Vbattk_{nom}(k)}\right]$, and the $SoC(k)$ can be defined as:

$$SoC(k,t) = SoC(k,t-1) - \frac{1}{C_{bat}(k)*Vbat_{nom}(k)} * \left[P_{bat}(k,t)\Delta t\right], \quad \forall k,t \tag{1}$$

In this particular case, the considered system storage is an electric battery whose coefficient $\varphi_{bat}(k)$ is obtained (out of the optimization model) assuming a nominal voltage value $Vbat_{nom}(k)$ for the interval $\Delta t$. The $\varphi_{batk}$ coefficient is related to the energy capacity and the SoC as is shown in (1).

$$\varphi_{bat}(k) = \frac{1}{C_{bat}(k) * Vbat_{nom}(k)}, \quad \forall k \tag{2}$$

Likewise, $SoC_{max}(k)$ is selected to allow the battery to be fully charged without overcharging ($SoC_{max}(k) = 100\%$) and $SoC_{min}$ is chosen to limit the depth of discharge (DoD) accordingly with the recommendation of the IEEE1561-2007 standard [20] ($SoC_{min}(k) = 50\%$).

Regarding the proposed penalties, ceasing using the power available in the $i-th$ RES is penalized the cost $\xi(i)$, and in the same way, having the $k-th$ ESS fully charged at $t=T$ is rewarded with $\chi(k)$.

where $P_g(i,t)$ correspond to the estimated power of the sources, $COST$ is whole cost paid by the user (including penalties), and $P_{bat}(k,t)$ and $SOC(t)$ are the power and the SoC of the ESS, respectively.

### B. Optimization Formulation

The optimization problem to be solved is the LP presented below:

*1) Energy Sources:* As a general approach, $P_g(i,t)$ is the power of the sources $i = 1, 2, ..., n_g$ at each $t$, and it is a positive variable delimited by the maximum power that can be provided, $P_{g_{max}}(i,t)$.

$$0 \le P_g(i,t) \le P_{g_{max}}(i,t), \quad \forall i,t \tag{3}$$

In the case of RES, $P_{g_{max}}$ is a set of variable data defined by a 24-h-ahead power predictor for each $t$.

*2) Energy Storage:* The $SoC(k,t)$ in the $k-th$ storage system of the microgrid can be represented in terms of its power as:

$$SoC(k,t) = SoC(k,t-1) - \varphi_{bat}(k) * \left[P_{bat}(k,t)\Delta t\right], \quad \forall k,t \tag{4}$$

considering that at $t=1$, $SoC(k,t-1)$ is replaced by the given initial condition $SoC(k,0)$.

Apart from that, the $SoC(k,t)$ at each $t$ is bounded in the range:

$$SoC_{min}(k) \le SoC(k,t) \le SoC_{max}(k), \quad \forall k,t \tag{5}$$

The values of $SoC_{min}(k)$ and $SoC_{max}(k)$ are defined following the recommendation of the IEEE1561-2007 standard [20].

Additionally, the global balance of the SoC is assured by establishing the condition:

$$\sum_{t=1}^{T-1} SoC(k,t+1) - SoC(k,t) \ge 0, \quad \forall k \tag{6}$$

*3) Energy Balance:* The demand must be supplied by the sources and the storage system.

$$\sum_{i=1}^{n_g} P_g(i,t)\Delta t + \sum_{k=1}^{n_k} P_{bat}(k,t)\Delta t = P_L(t)\Delta t + P_{losses}, \quad \forall t,k,i \tag{7}$$

Should be noted that, when $P_{bat}$ is positive, the storage system gives energy to the load (it is being discharged) and when is negative, it takes energy from the sources (it is being charged).

*4) Objective Function:* The objective is to minimize operating costs that the user must pay for the energy provided by the sources.

$$\text{COST} = \sum_{i=1}^{n_g}\sum_{t=1}^{T} \left[P_g(i,t)\Delta t\right] * C(i,t), \quad \forall i,t \tag{8}$$

The main grid ($i=1$) has a cost $C(1,t)$ that varies each $t$ while production costs of the renewable sources are zero.

*5) Proposed penalties:* Two penalties are proposed to be incorporated in the objective function and compare the performance of the resources in the MG by combining the resulting cases:

*a) Penalty 1:* This penalty takes into account the non-used power generated by renewable resources $t$ $(P_g(i,t) < P_{g_{max}}(i,t))$.

$$\sum_{i=1}^{n_g}\sum_{t=1}^{T}\xi(i)*[P_{g_{max}}(i,t)\Delta t - P_g(i,t)\Delta t]\,,\ \ \forall t, i \in RES \tag{9}$$

The parameter $\xi(i)$ corresponds to the penalization cost and it is zero for the main grid.

*b) Penalty 2:* Additionally, a reward for having charged the ESS at the last $t$ is set as a global condition.

$$\chi(k) * [SoC(k,T) - SoC(k,1)]\,,\ \ \forall k \tag{10}$$

In this case, the constraint (6) is discarded.

Given the above points, four strategies are scheduled and simulated: the basic cost function and the ones that result for adding the previously defined penalties into the optimization process according to the combinations presented in Table III.

TABLE III. STRATEGIES TO BE IMPLEMENTED

| | No penalty 1 | With penalty 1 |
|---|---|---|
| No penalty 2 | Strategy 1 | Strategy 3 |
| With penalty 2 | Strategy 2 | Strategy 4 |

To compare the strategies, the function *fitness* is defined by adding the strategies:

$$\text{Fitness} = \sum_{i=1}^{n_g}\sum_{t=1}^{T}[P_g(i,t)\Delta t] * C(i,t) +$$
$$\sum_{i=1}^{n_g}\sum_{t=1}^{T}\xi(i) * [P_{g_{max}}(i,t)\Delta t - P_g(i,t)\Delta t] +$$
$$\chi(k) * [SoC(k,T) - SoC(k,1)] \tag{11}$$

In this case, $\xi(i)$ is proportional to the day-ahead cost of the grid and $\chi(k)$ is set as a constant.

## IV. Simulation Results

The scheduling process is performed by using real data of wind speed and solar irradiance of a winter day and using proper models for the WT and PV 24-h-ahead PV and WT power prediction. The input data of the obtained RES power and the elementary cost of using the energy from the grid are presented in Fig. 2.

Along with, a constant initial condition of $SoC(k,0)$ $(SoC(k,0) = 75\%)$ is set for performing the simulations.

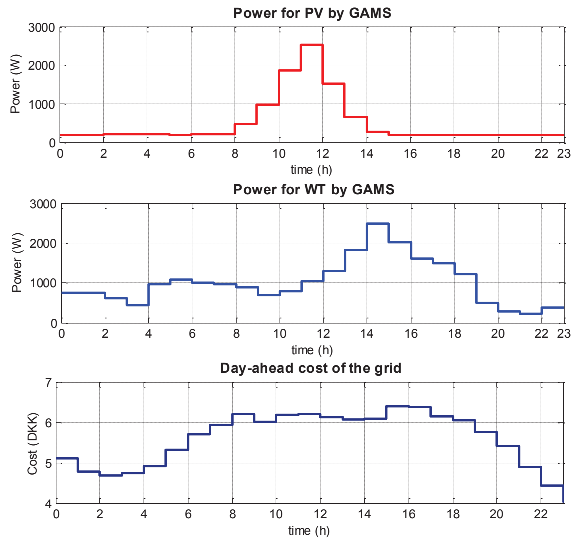


Fig. 2. Input data for scheduling: (red line) PV forecast power, (blue line) WT forecast power, (dark-blue line) cost of energy of grid

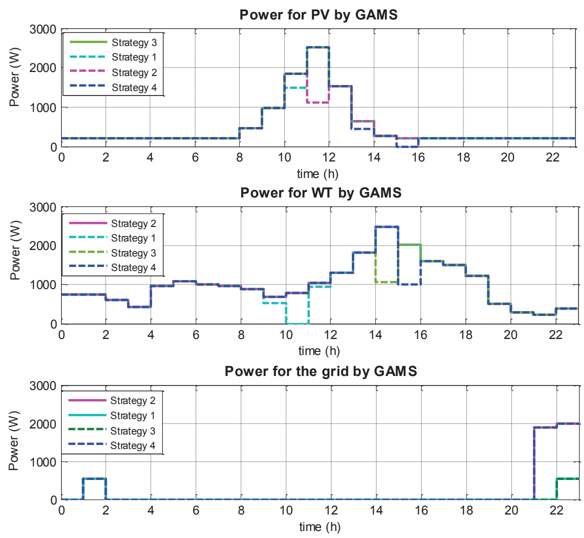


Fig. 3. Scheduled power for each strategy. Top down: PV scheduled power, WT scheduled power and scheduled power for the grid.

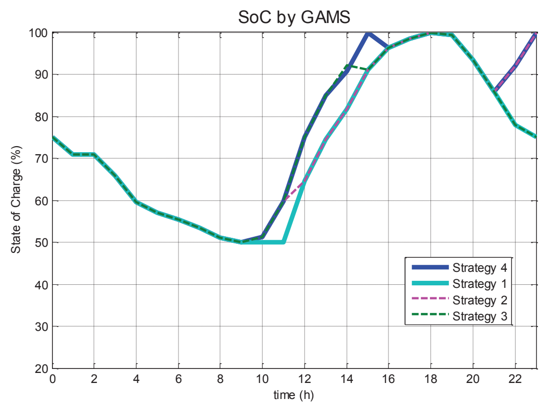


Fig. 4. Expected SoC by GAMS for each strategy.

## A. Generation scheduling

The optimization problem is included in the algebraic model language GAMS and the solver CPLEX is used for obtained the scheduling data. The results are presented in Fig. 3 whereas the SoC that is expected in this model is shown in Fig. 4.

It can be seen that all the strategies make the SoC of the ESS stay in the boundaries and also be charged for a while during the day. Moreover, the strategies 1 and 3 (which do not include the second penalty) use the power of the grid at the same times and in turn, for less time than the strategies 2 and 4, as expected in order to charge the ESS at the last interval of time.

In particular, the strategy 1 (cost function without penalties) uses the grid for a short time but, it cuts off the available power of the RES when the ESS is not charged ($SoC(k, 10) = 50\%$) what is not optimal. The strategy 2, which includes, the second penalty, has a similar behavior regarding to the cutting but taking more energy from the grid.

Meanwhile, the strategy 3 takes energy from the grid for short time and cuts off the power of the RES when the SoC of the ESS is high. Additionally, the strategy 4 cuts the power of the RES when the SoC is the highest compared with the other strategies, however, the energy that it takes from the grid is high. In qualitative terms, the strategy 3 utilizes the energy from the grid, cuts off the RES power in a convenient time interval and hold the ESS with a global balance since the inclusion of the constraint (6).

Furthermore, by scheduling the strategies in GAMS, the fitness function is calculated for each strategy and presented in the Table IV

TABLE IV. FITNESS FOR DIFFERENT STRATEGIES

| Case | Cost (DKK) |
|---|---|
| Strategy 1 | 11.6513 |
| Strategy 2 | 21.6778 |
| Strategy 3 | 2.3658 |
| Strategy 4 | 21.6811 |

In light of the above, the strategy 3 are certainly the best one for using adequately the RES power and the power of the grid. On the contrary, the strategies 2 and 4 (which include penalization 2) have the worst performance regarding the defined objectives.

As an additional test, the same scenario is used with these two strategies for the next day (same input data) but using $SoC(k, 0) = 100\%$ and the fitness functions are 38.9427 and 49.7895 which means that the final value of the SoC does not imply better results for the active power of the resources at the next day.

## B. Simulation of MG without scheduling

The autonomous mode of the MG (i.e. without using scheduling set points, the RES are in MPPT mode and the grid and the battery switch between CCM and VCM) is simulated by using a Simulink model. The simulation of the SOC are presented in Fig. 5. In this case, the energy from the RES are not used to charge the storage system since it is not fully charged at any time during the day.

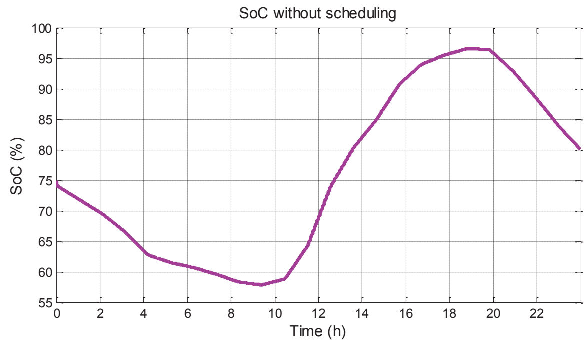


Fig. 5. SOC for predicted and perturbed input data

The costs paid for using the scheduled power of the grid as function of the time are presented in Fig 6 (dashed line) together with the forecast cost of the energy getting from the grid (dark-blue solid line). It is noted that the energy of the grid is required when the power of the RES is less than the power requested for the load that, in this scenario, is for more than 12 hour of the day which means a higher operating cost for the user.

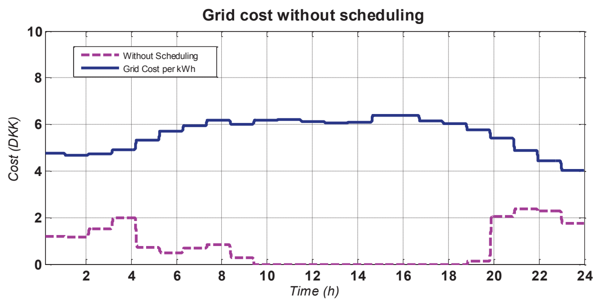


Fig. 6. Cost summary for the implemented strategies

In order to compare this behavior, the fitness function is evaluated and it results to be 22.549. To get back to the point and based on the given objectives, it is possible to have similar behavior with the autonomous mode (without perfoming scheduling) than with the reward of the SoC (penalty 2 that is strategies 2 and 4).

## C. Hardware in the loop results

Real-time simulation are obtained in the Intelligent MicroGrid Laboratory at the Aalborg University [21] to test the strategies previously presented in a microgrid model established with MATLAB/Simulink toolbox. The power of the energy resources using the different strategies are shown in Figs. 7, 10, 13 and 16 respectively. Each figure shows the active power of the PV, the WT, the grid

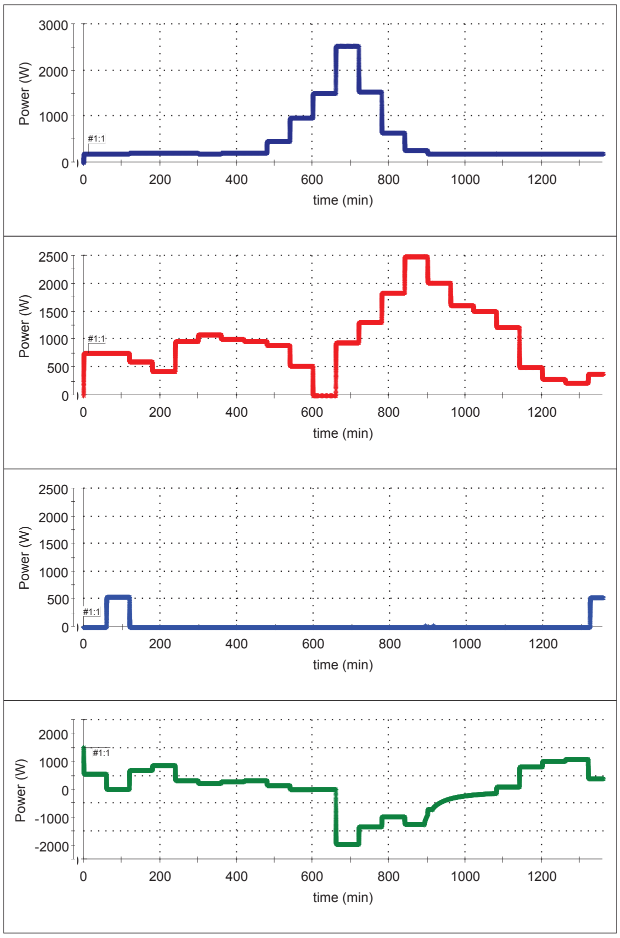


Fig. 7. Power of the devices using strategy 1. Top down: Power of PV, Power of WT, Power of the grid, Power of the ESS

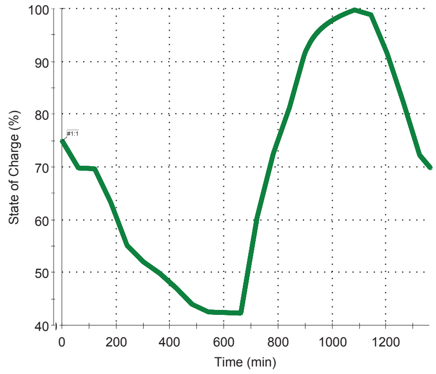


Fig. 8. SoC of the ESS using strategy 1.

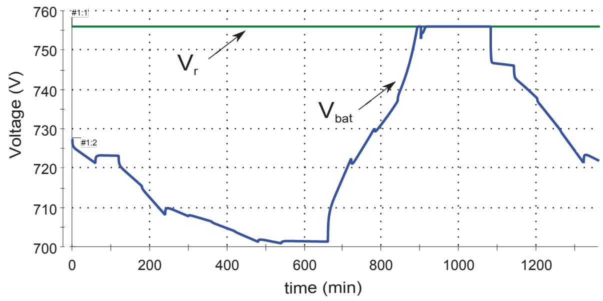


Fig. 9. Voltage of the battery using strategy 1.

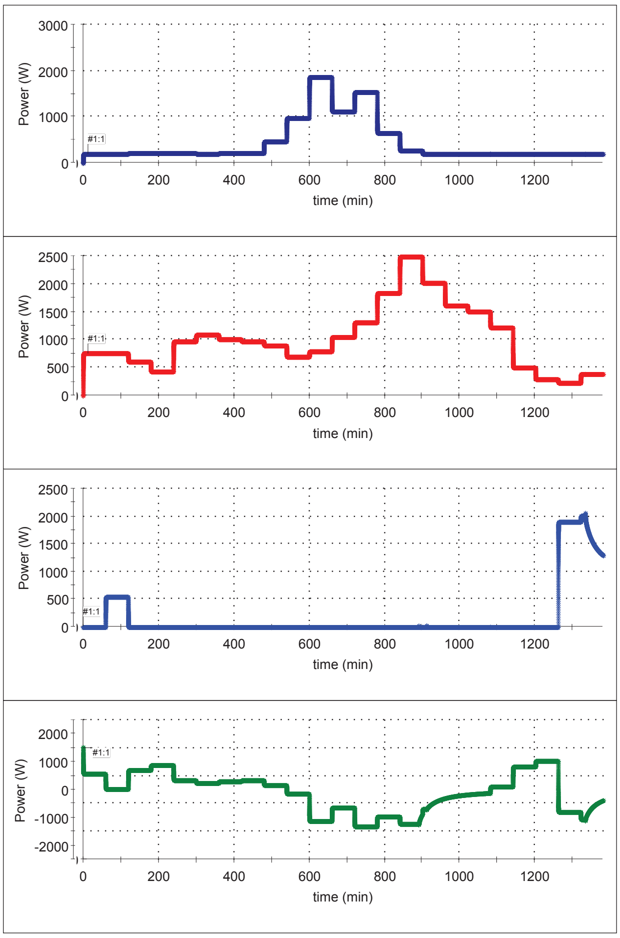


Fig. 10. Power of the devices using strategy 2. Top down: Power of PV, Power of WT, Power of the grid, Power of the ESS

and the ESS. The power of the generators follows the reference defined by the scheduling and the ESS is charged or discharged in accordance to the generated/consumed power unbalance. The process of charge and discharge is more evident by means of the SoC in Figs. 8, 11, 14 and 17, for each strategy respectively.

In addition, the changes at the two-stage procedure for charging the battery can be seen through the battery voltage behavior shown in Figs. 9, 12, 15 and 18. The SoC is similar to the expected by the scheduling but the DoD is bigger because of the granularity of the optimization model. At this case, detailed model of the battery as proposed in [18] is used for simulating the battery.

Comparing the charging time exhibited by batteries with different strategies, the worst performance is obtained with the strategy 4 (Fig. 18) whereas with the strategy 3, the battery is at the charged mode for more time (Fig. 15).

## V. CONCLUSIONS AND FUTURE WORK

The optimization problem of minimizing operating costs has been established and it has been enhanced by adding two penalties in order to improve the behavior of the system. From the economic dispatch results, it

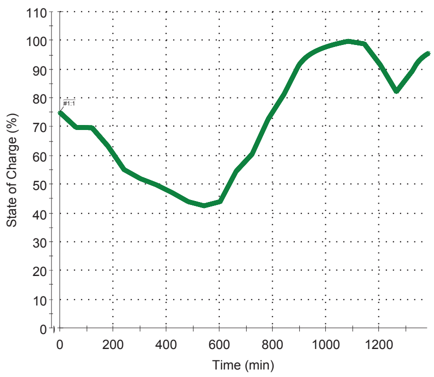


Fig. 11. SoC of the ESS using strategy 2.

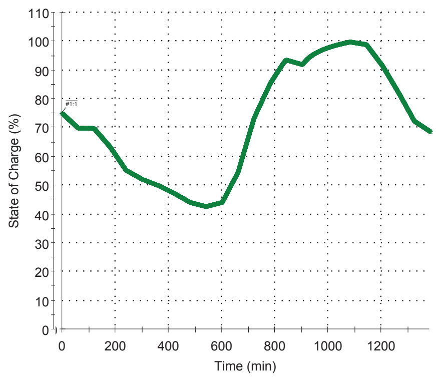


Fig. 14. SoC of the ESS using strategy 3.

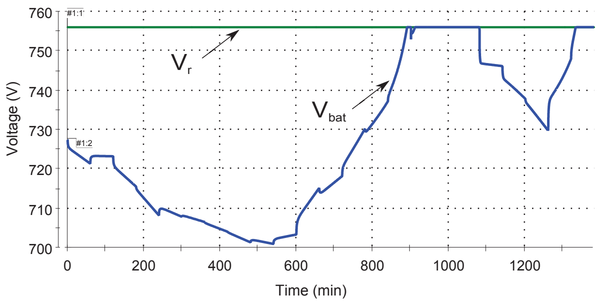


Fig. 12. Voltage of the battery using strategy 2.

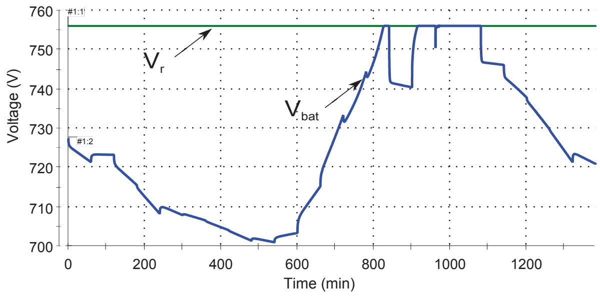


Fig. 15. Voltage of the battery using strategy 3.

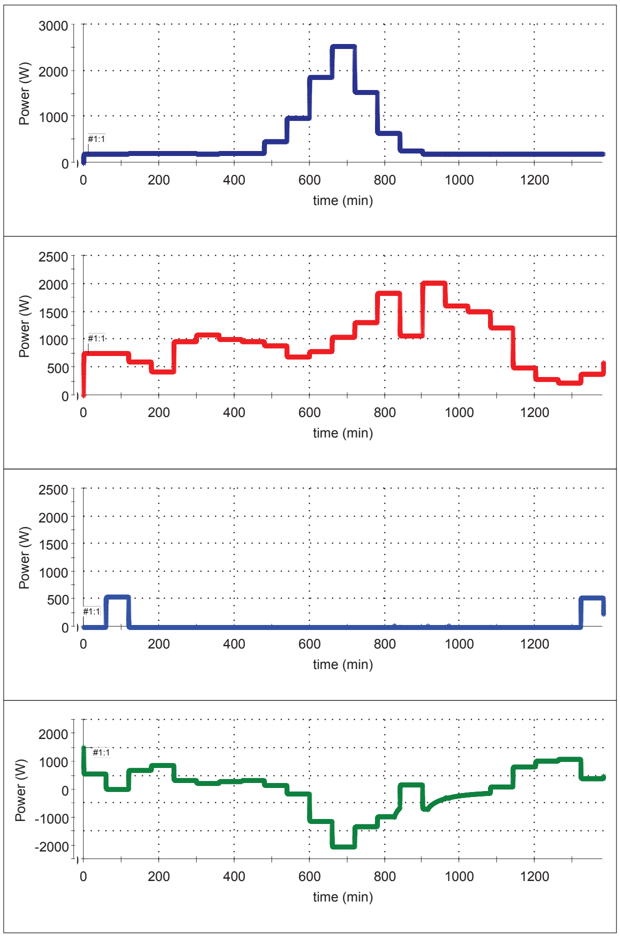


Fig. 13. Power of the devices using strategy 3. Top down: Power of PV, Power of WT, Power of the grid, Power of the ESS

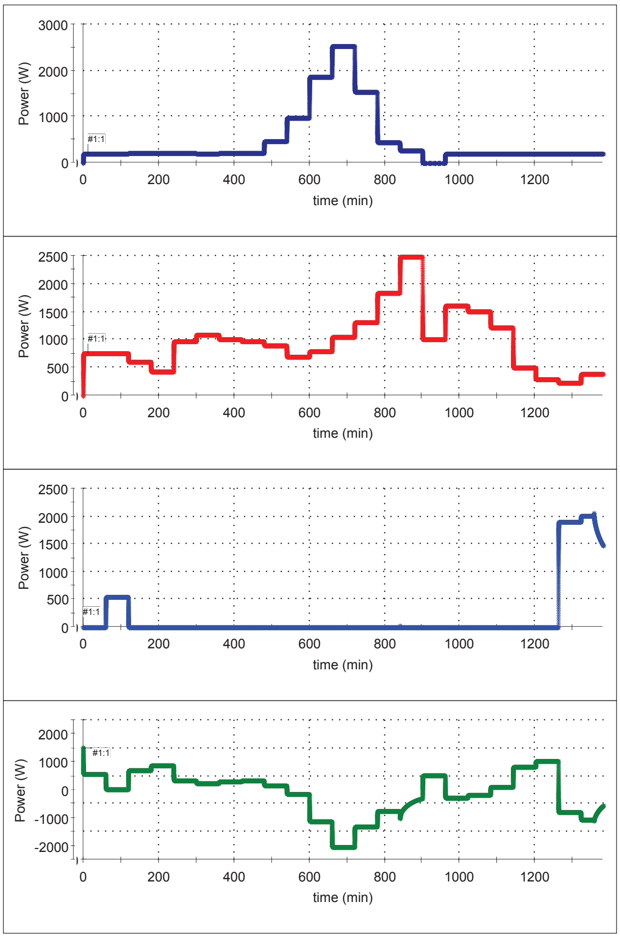


Fig. 16. Power of the devices using strategy 4. Top down: Power of PV, Power of WT, Power of the grid, Power of the ESS

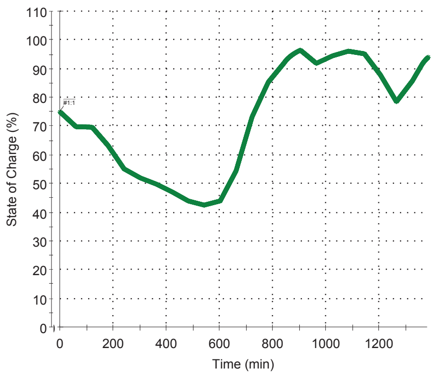


Fig. 17. SoC of the ESS using strategy 4.

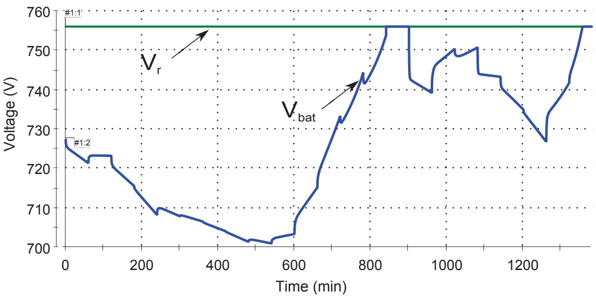


Fig. 18. Voltage of the battery using strategy 4.

is possible to conclude that, despite the granularity of the optimization model, it is suitable to schedule the references of the active power and predict the behavior of the SoC in the battery. Furthermore, the inclusion of the penalty related to the use of the RES has improved the scheduling process while the reward of the final SoC has degraded the cost even having into account the next day. Besides, the penalty of the use of RES represents a bigger SoC of the battery during the day even when the active power of the battery is not included as a decision variable in the objective function. As future work, the optimization problem should be improved by taking into account power losses and the operation modes of the battery. Additionally, this approach should implement in a rolling horizon scheduling to improve the DoD of the battery.

## References


[1] Q. Jiang, M. Xue and G. Guangchao, "'Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes"', Power Systems, IEEE Transactions on, Vol. 28, nr. 3, pp. 3380-3389, 2013.

[2] J. de Matos, F. e Silva, and L. Ribeiro, Power control in ac isolated microgrids with renewable energy sources and energy storage systems, IEEE Transactions on Industrial Electronics,, vol. PP, no. 99, pp. 11, 2014. This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TIE.2014.2367463.

[3] M. Iqbal, M. Azam, M. Naeem, A.S. Khwaja, A. Anpalagan, Optimization classification, algorithms and tools for renewable energy: A review, Renewable and Sustainable Energy Reviews, Volume 39, November 2014, Pages 640-654

[4] Wang, Chengshan ; Mengxuan Liu; Li Guo, "Cooperative operation and optimal design for islanded microgrid," Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES , vol., no., pp.1,8, 16-20 Jan. 2012

[5] Marra, F.; Guangya Yang; Traeholt, C.; Ostergaard, J.; Larsen, E., "A Decentralized Storage Strategy for Residential Feeders With Photovoltaics," Smart Grid, IEEE Transactions on , vol.5, no.2, pp.974,981, March 2014

[6] Kanchev, H.; Di Lu; Colas, F.; Lazarov, V.; Francois, B., "Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications," Industrial Electronics, IEEE Transactions on , vol.58, no.10, pp.4583,4592, Oct. 2011

[7] Kanchev, H.; Lazarov, V.; Francois, B., "Environmental and economical optimization of microgrid long term operational planning including PV-based active generators," Power Electronics and Motion Control Conference (EPE/PEMC), 2012 15th International , vol., no., pp.LS4b-2.1-1,LS4b-2.1-8, 4-6 Sept. 2012

[8] Malysz, P.; Sirouspour, S.; Emadi, A., "MILP-based rolling horizon control for microgrids with battery storage," Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE , vol., no., pp.2099,2104, 10-13 Nov. 2013

[9] Hooshmand, A.; Asghari, B.; Sharma, R., "'A novel cost-aware multi-objective energy management method for microgrids,"' Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES , vol., no., pp.1,6, 24-27 Feb. 2013

[10] Zhixin Miao; Ling Xu; Disfani, V.R.; Lingling Fan, "'An SOC-Based Battery Management System for Microgrids,"' Smart Grid, IEEE Transactions on , vol.5, no.2, pp.966,973, March 2014

[11] Beltran, H.; Bilbao, E.; Belenguer, E.; Etxeberria-Otadui, I.; Rodriguez, P., "'Evaluation of Storage Energy Requirements for Constant Production in PV Power Plants,"' Industrial Electronics, IEEE Transactions on , vol.60, no.3, pp.1225,1234, March 2013

[12] Yongheng Yang; Blaabjerg, F.; Huai Wang, "'Constant power generation of photovoltaic systems considering the distributed grid capacity,"' Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE , vol., no., pp.379,385, 16-20 March 2014

[13] Vasquez, J.C.; Guerrero, J.M.; Miret, J.; Castilla, M.; de Vicua, L.G., "Hierarchical Control of Intelligent Microgrids," Industrial Electronics Magazine, IEEE , vol.4, no.4, pp.23,29, Dec. 2010

[14] Guerrero, J.M.; Vásquez, J.C.; Matas, J.; de Vicuña, L.G.; Castilla, M., "'Hierarchical Control of Droop-Controlled AC and DC MicrogridsA General Approach Toward Standardization,"' Industrial Electronics, IEEE Transactions on , vol.58, no.1, pp.158,172, Jan. 2011.

[15] I. S. C. C. 21, Ieee guide for optimizing the performance and life of lead-acid batteries in remote hybrid power systems, 2008.

[16] Niiranen, J.; Komsi, R.; Routimo, M.; Lahdeaho, T.; Antila, S., "Experiences from a back-to-back converter fed village microgrid," Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES , vol., no., pp.1,5, 11-13 Oct. 2010

[17] Wu, D.; Tang, F.; Dragicevic, T.; Vasquez, J.C.; Guerrero, J.M., "Autonomous Active Power Control for Islanded AC Microgrids With Photovoltaic Generation and Energy Storage System," Energy Conversion, IEEE Transactions on , vol.29, no.4, pp.882,892, Dec. 2014

[18] Dragicevic, T.; Guerrero, J.M.; Vasquez, J.C.; Skrlec, D., "Supervisory Control of an Adaptive-Droop Regulated DC Microgrid With Battery Management Capability," Power Electronics, IEEE Transactions on , vol.29, no.2, pp.695,706, Feb. 2014

[19] D. Linden and T. Reddy, Handbook of batteries. McGraw-Hill handbooks, McGraw-Hill, 2002.

[20] IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power System, IEEE Std. 1561-2007, April 2008.

[21] Research Programme in MicroGrids, Aalborg University, 2014-08-06, http://www.et.aau.dk/research-programmes/microgrids